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Analytical Solutions of Josephson Junctions Dynamics in a Resonant Cavity for Extended Dicke Model

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Abstract : The Dicke model is a key tool for the description of correlated states of quantum atomic systems, excited by resonant photon absorption and subsequently emitting spontaneous coherent radiation in the superradiant state. The Dicke Hamiltonian (DH) is successfully used for the description of the dynamics of the Josephson Junction (JJ) array in a resonant cavity under applied current. In this work, we have investigated a generalized model, which is described by DH with a frustrating interaction term. This frustrating interaction term is explicitly the infinite coordinated interaction between all the spin half in the system. In this work, we consider an array of N superconducting islands, each divided into two sub-islands by a Josephson Junction, taken in a charged qubit / Cooper Pair Box (CPB) condition. The array is placed inside the resonant cavity. One important aspect of the problem lies in the dynamical nature of the physical observables involved in the system, such as condensed electric field and dipole moment. It is important to understand how these quantities behave with time to define the quantum phase of the system. The Dicke model without frustrating term is solved to find the dynamical solutions of the physical observables in analytic form. We have used Heisenberg’s dynamical equations for the operators and on applying newly developed Rotating Holstein Primakoff (HP) transformation and DH we have arrived at the four coupled nonlinear dynamical differential equations for the momentum and spin component operators. It is possible to solve the system analytically using two-time scales. The analytical solutions are expressed in terms of Jacobi's elliptic functions for the metastable ‘bound luminosity’ dynamic state with the periodic coherent beating of the dipoles that connect the two double degenerate dipolar ordered phases discovered previously. In this work, we have proceeded the analysis with the extended DH with a frustrating interaction term. Inclusion of the frustrating term involves complexity in the system of differential equations and it gets difficult to solve analytically. We have solved semi-classical dynamic equations using the perturbation technique for small values of Josephson energy EJ. Because the Hamiltonian contains parity symmetry, thus phase transition can be found if this symmetry is broken. Introducing spontaneous symmetry breaking term in the DH, we have derived the solutions which show the occurrence of finite condensate, showing quantum phase transition. Our obtained result matches with the existing results in this scientific field.

Keywords : Dicke Model, nonlinear dynamics, perturbation theory, superconductivity
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